

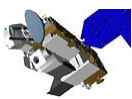
Aura to Exit the A-Train?

Aura Extended Mission Operations Concept

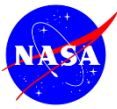
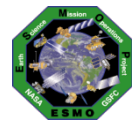
August 27, 2019



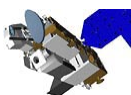
**Aura Mission Director
Dominic Fisher
(301) 286-3171
dominic.m.fisher@nasa.gov**



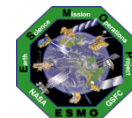
Background



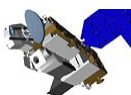
- The Aura Project Science Office (PSO), in conjunction with ESMO, instrument Principle Investigators and operations teams, have been assessing the feasibility of Aura leaving the A-Train in 2021 as a means of lengthening mission life by conserving fuel.
- They weighed the likely impact of leaving on the instrument's ability to maintain science-quality and trend-quality long-term data records, the highest priority of the Aura Mission.
- An important consideration is that MLS collects unique data for several important stratospheric constituents and there is no follow-on mission planned for an instrument with similar capabilities as MLS.



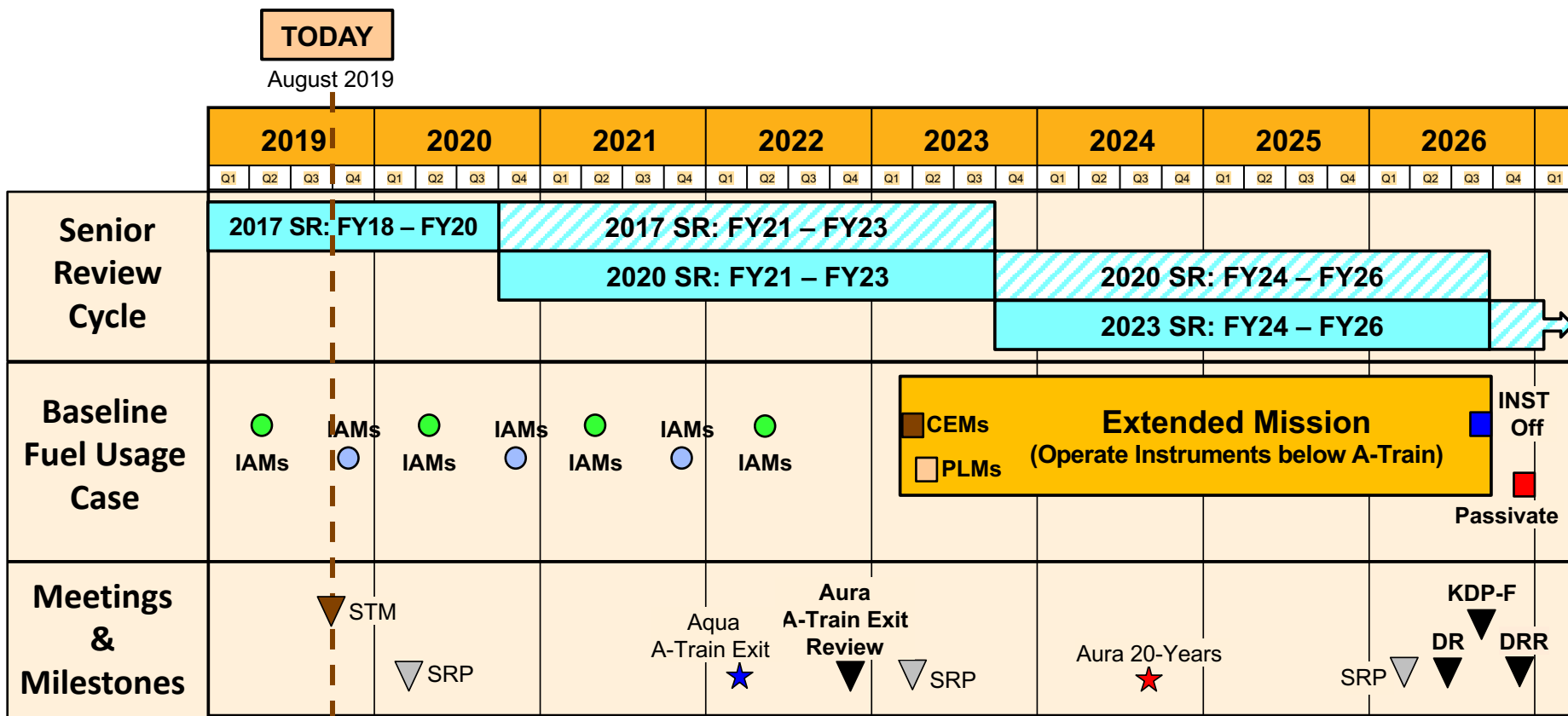
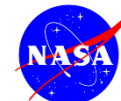
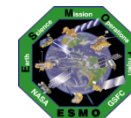
Introduction



- After careful consideration, all parties recommend that the satellite **remain in the A-Train until 2023**
- This will provide the best opportunity for collecting high quality data for the longest duration (**~19 years in the A-Train + ~2-3 years at lower drifting orbit**)
- In advance of any constellation safety concerns and subsequent fuel limitations, the satellite would exit the A-Train constellation and lower perigee to meet the agency 25-year reentry requirement
- After constellation exit and perigee lowering maneuvers, the goal would be to leave the instruments on and continue to collect Science-quality data while lower and drifting, though careful data processing would be required
- Depending on the health of the satellite and the ability to maintain safe operations, the goal will be to maintain operations past 2025 and commence with instrument and mission decommissioning activities when NASA Headquarters deems necessary



Aura Extended Mission Timeline



▼ **STM** – Aura Science Team Meeting (2019)

▼ **SRP** – Senior Review Proposal

■ Senior Review Funding (Approved)

■ Senior Review Funding (Preliminary Guideline)

● **IAMs** – Spring Inclination Adjust Maneuvers

● **IAMs** – Fall Inclination Adjust Maneuvers

■ **CEMs** – Constellation Exit Maneuvers

■ **PLMs** – Perigee Lowering Maneuvers

■ **INST Off** – Power down instruments

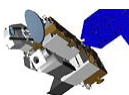
■ **Passivate** – Spacecraft bus passivation

▼ **A-Train Exit Review** (~late 2022)

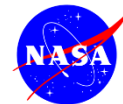
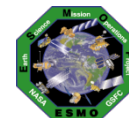
▼ **DR** – Decommissioning Review

▼ **KDP-F** – HQ Key Decision Point to proceed with Phase F

▼ **DRR** – Disposal Readiness Review



Considerations



Exiting the A-train and altering the operational orbit has several important factors to consider:

Science Considerations –

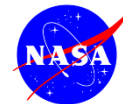
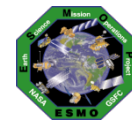
- Maintaining long-term, science quality data
- Continuing science synergy with other satellites

Spacecraft Considerations –

- Requires a retrograde maneuver capability for Constellation Exit Maneuvers (CEMs) and Perigee Lowering Maneuvers (PLMs)
- Requires ability to maintain operations at lower altitude, with increasing beta angle and drifting Mean Local Time (MLT)
- Power generation and thermal profiles will change as the orbit and beta angle shifts

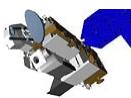


Considerations

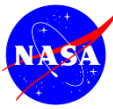
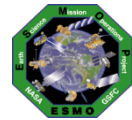


Instrument Considerations –

- During the CEMs and PLMs, the instruments will need to:
 - Identify safe instrument configurations for retrograde maneuvers
 - Examine if there will be any thermal, sun exposure, or contamination concerns
- In order to operate at the new lower orbit, the instruments will need to:
 - Determine if new thermal and sun exposure conditions will pose any concerns
 - Develop new operational products and procedures (i.e., calibration sequences)
- Microwave Limb Sounder (MLS) is not constrained to maintain a particular beta angle or MLT for lighting conditions
 - Careful analysis of the data will be required to maintain science-quality, trend-quality data for MLS, but it is feasible
- Ozone Monitoring Instrument (OMI) is constrained currently to maintain particular beta angle (18.3 deg. – 31.2 deg) for instrument calibration



Spacecraft Limitations



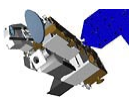
The main Spacecraft Life Limiting Items include:

Fuel Limitations –

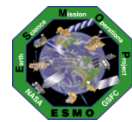
- With baseline fuel usage plan, predictions show fuel will reach a limit in **2023**
- With alternate fuel usage plan being considered, benefits have been weighed against impacts towards science and bus subsystems in new orbit profile
 - Implications on power generation and thermal constraints with new beta angle

Power Limitations –

- **Solar Array Power Generation**
 - With current pace of solar string degradation and current spacecraft load, predictions show power margins will start to be a concern in **~2025**
- **Battery Power Storage**
 - No lost battery cells at this point, predictions have shown that the capacity of the cells will be able to support the max depth-of-discharge limit until **~2029**
- Spacecraft load management schemes could be altered to reduce the required power necessary



Aura Fuel Usage Cases



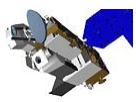
There have been two cases under consideration for fuel usage:

Baseline Fuel Usage Case -

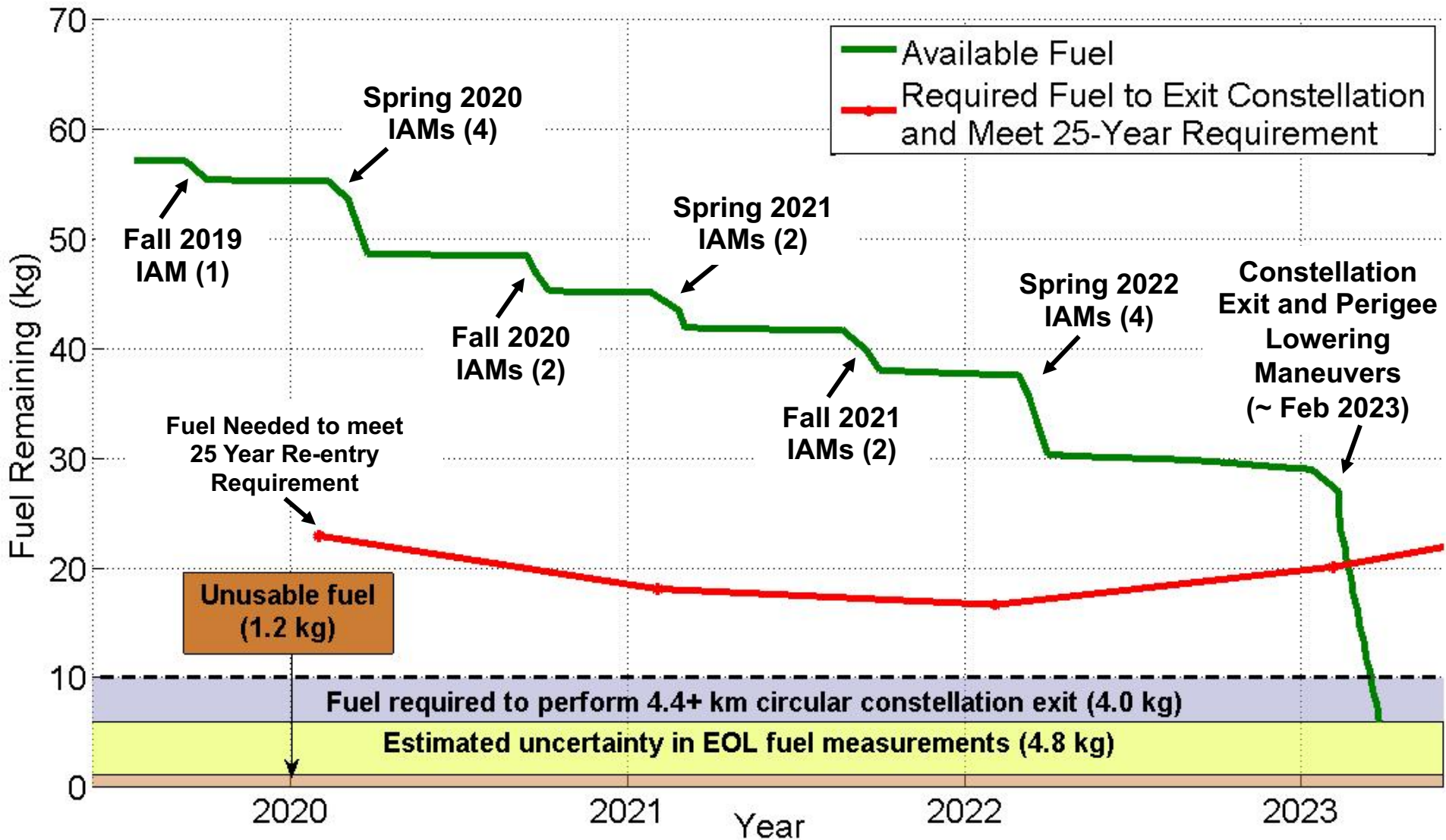
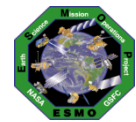
- Maintain MLT and WRS-2 Ground Track requirements until the DAS 25-year re-entry fuel limit is reached in **~2023**
 - Perform Inclination Adjust Maneuvers (IAMs) to maintain Mean Local Time (MLT)
 - Perform Drag Make-up Maneuvers (DMUs) to maintain Ground Track Error (GTE)

Alternate Fuel Usage Case (i.e., Early Exit from the A-Train) -

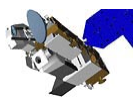
- Once OMI and TROPOMI have a minimum of 2 years of overlap, fuel saving schemes may be a consideration – **after Spring 2020**
 - Perform full IAM Series in 2019 & 2020, stop annual IAMs after 2020
 - Exit A-Train after Spring 2021 (lower 4.4 km in SMA)
 - Allow MLT and Solar Beta Angle to drift
 - Perform periodic DMUs to maintain ground track and frozen orbit



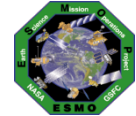
Baseline Fuel Usage Case



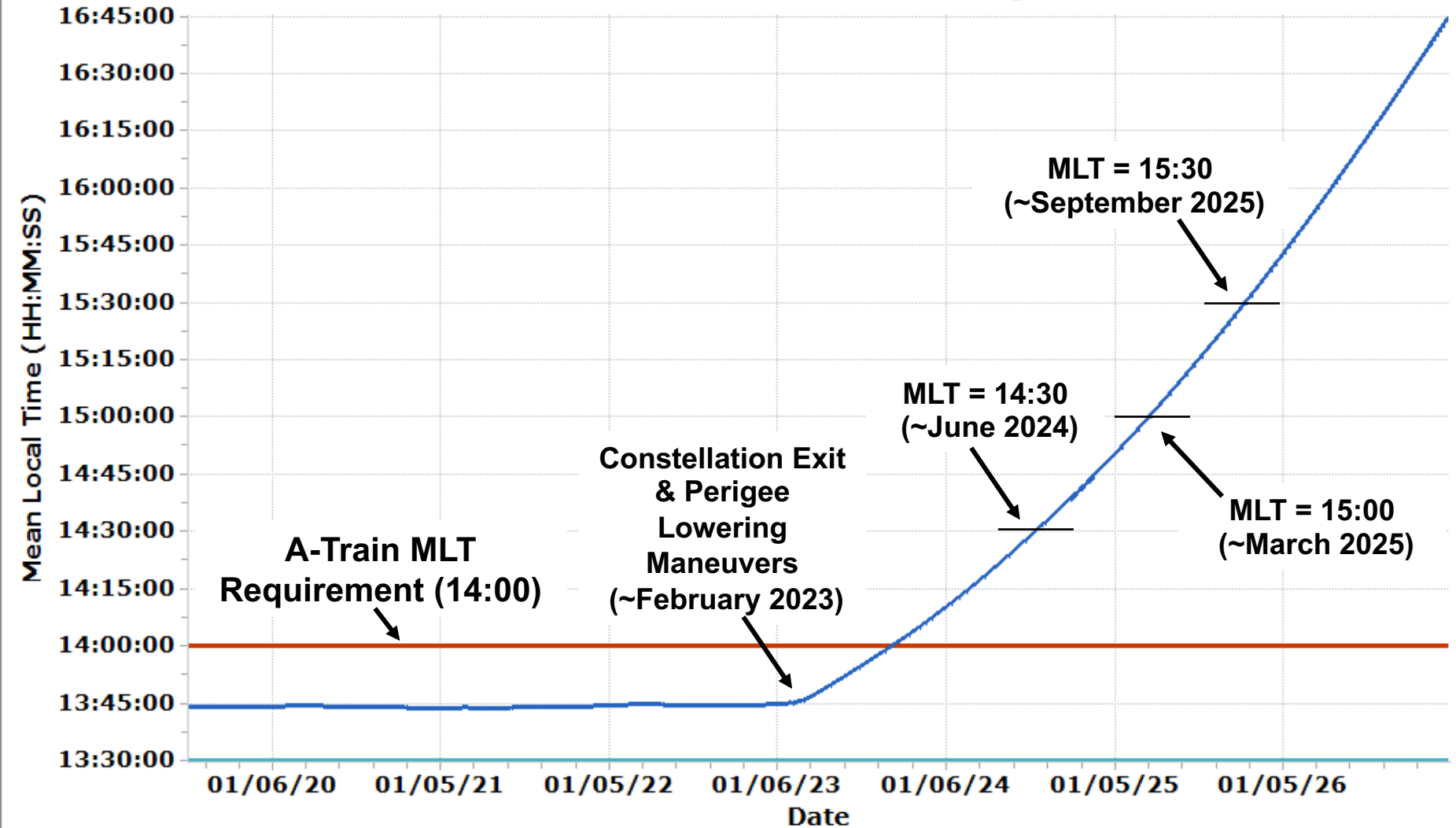
Aura DAS End of Life Predictions
(Analysis Updated August 2019)



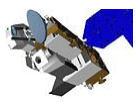
Mean Local Time (MLT) Drift



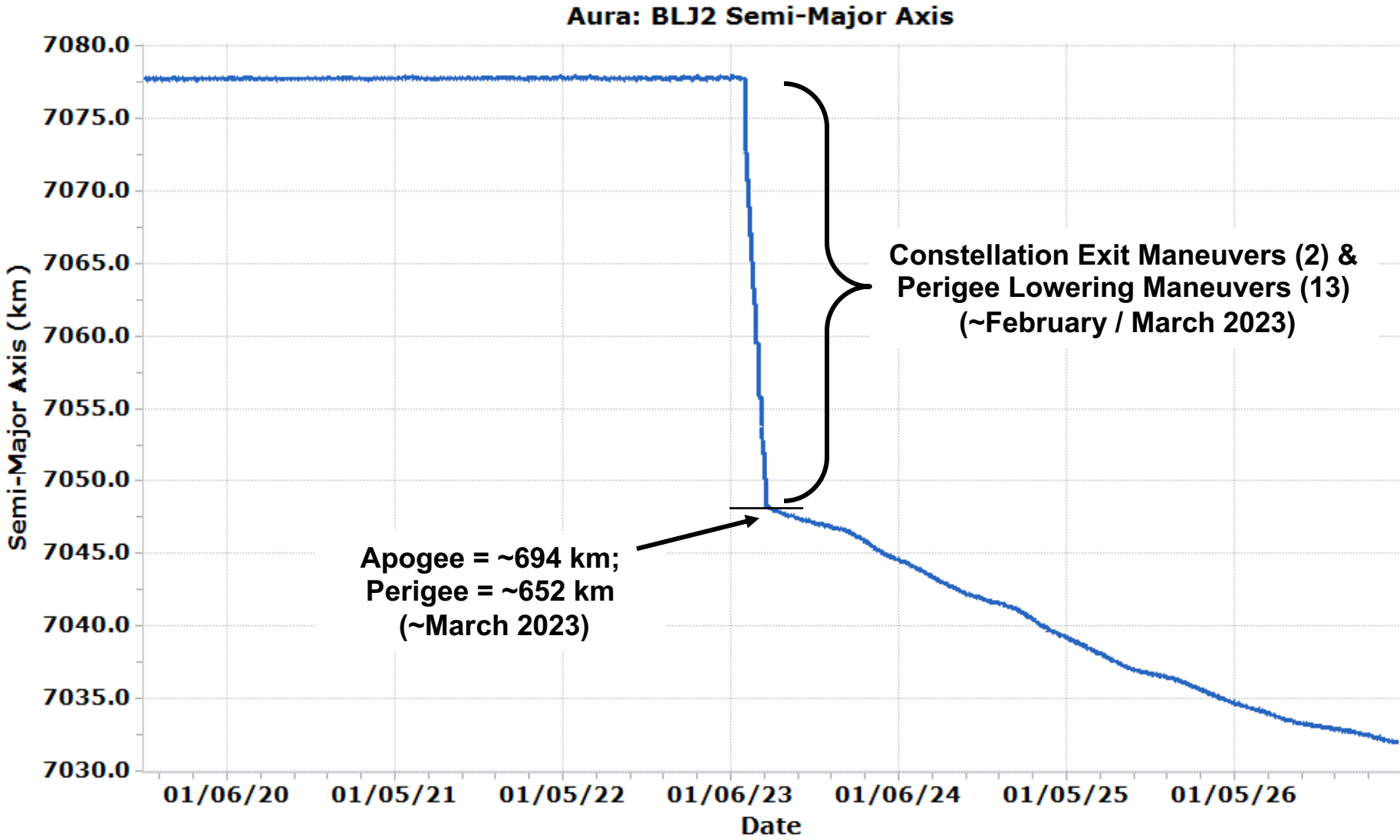
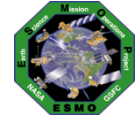
Aura: Mean Local Time at Ascending Node



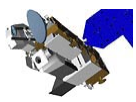
MLT Requirement: Constellation: 13:45 ± 15 min., Phasing with Aqua has kept MLT 13:38-13:50



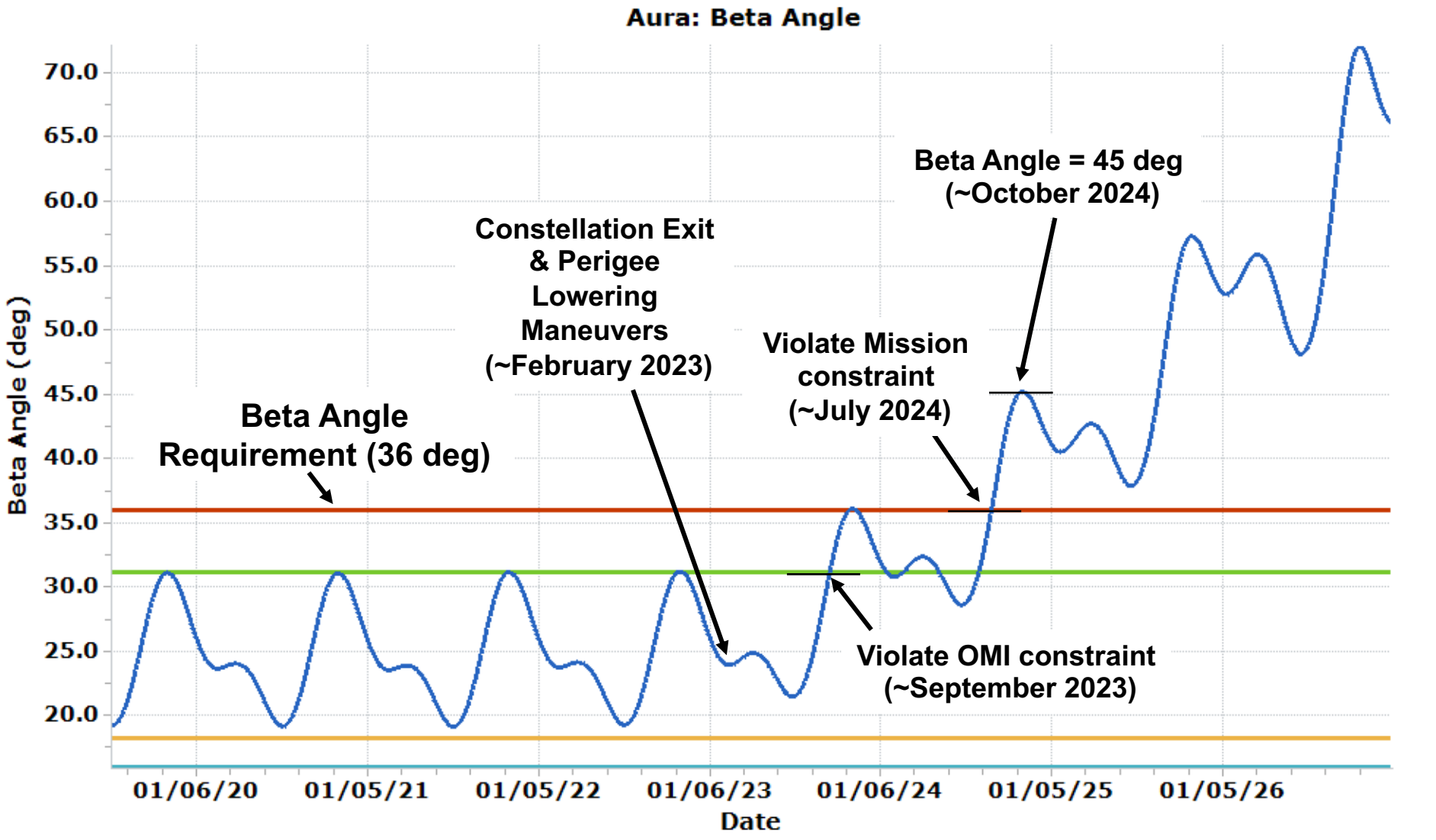
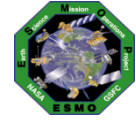
Semi-Major Axis (SMA) Lowering



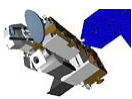
Semi-Major Axis: Constellation: 7077.7 km \pm 0.3 km



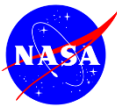
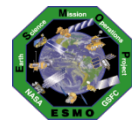
Beta Angle Drift



Beta Angle Requirement: Mission: 16 deg. – 36 deg., OMI: 18.3 deg. – 31.2 deg.



Aura Future Power Generation



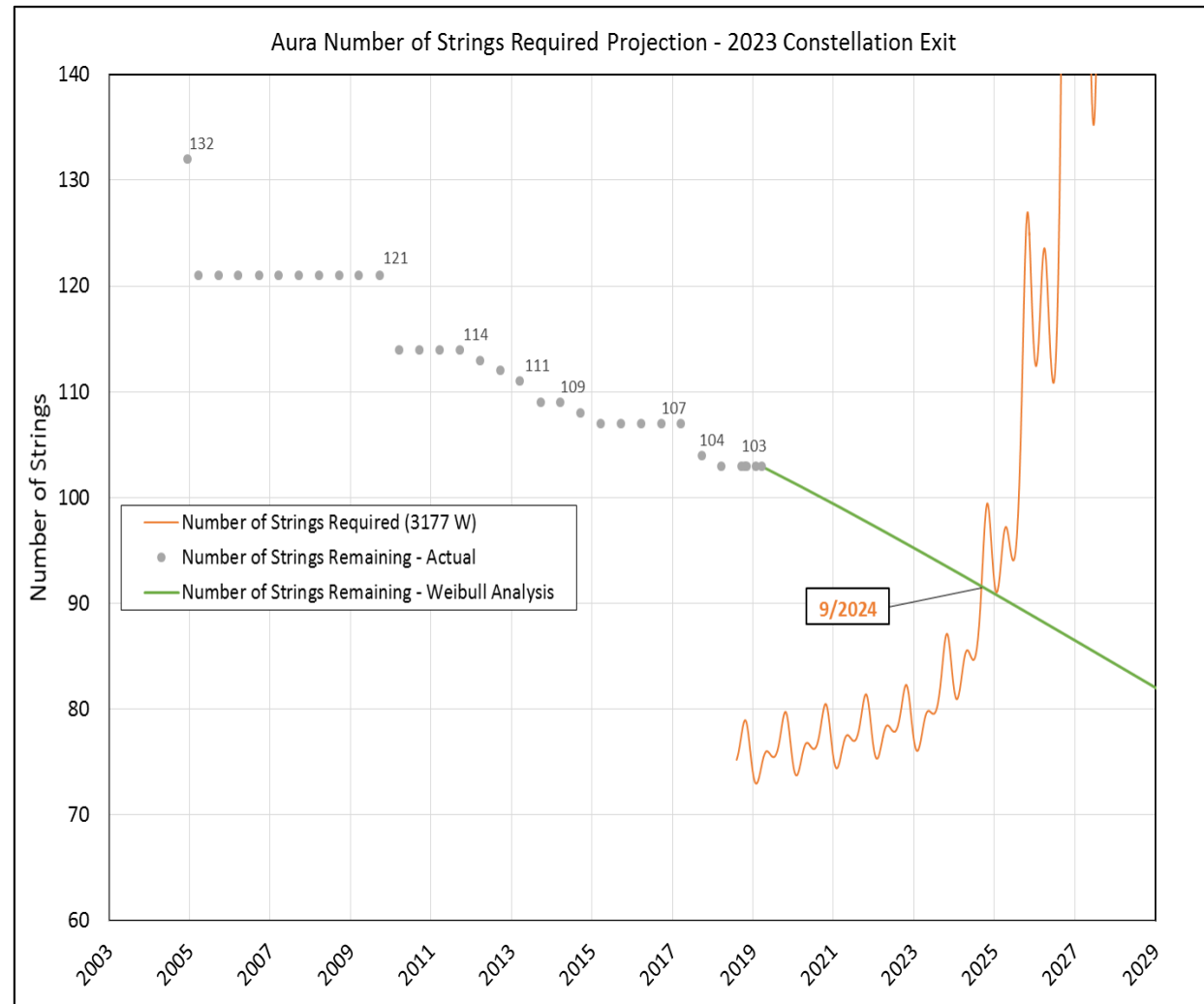
2023 A-Train Exit – Power Margin

Current power margin analysis estimates the **Minimum Required Power for Loads and Battery Charging = 3177 W**

Current best estimates for the 2023 exit case predict the power margin threshold would be violated in approximately **September 2024**

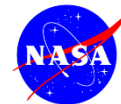
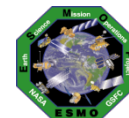
The number of strings required depends on what power we want to achieve and the Power per String

The solar array strings remaining projection comes from the Code 371 Weibull Analysis (updated 3/15/2019)

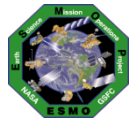
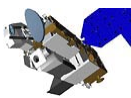




Conclusions



- **As far as saving fuel in order to extend mission life, there isn't a clear advantage to exiting the A-train early since the power generation concern has the potential to then be realized sooner (2023 vs. 2024)**
- **As far as operations, maintaining existing products and procedures for as long as possible allows for greater consistency and continuity while reducing the risk on the health and safety of the mission hardware**
- **From the spacecraft and instrument perspective, it is recommended to stay the course with the baseline fuel usage plan as it provides the best opportunity for collecting high quality data for the longest duration**



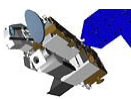
Questions?

Aura Mission Director

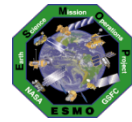
Dominic Fisher

(301) 286-3171

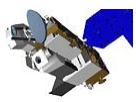
dominic.m.fisher@nasa.gov



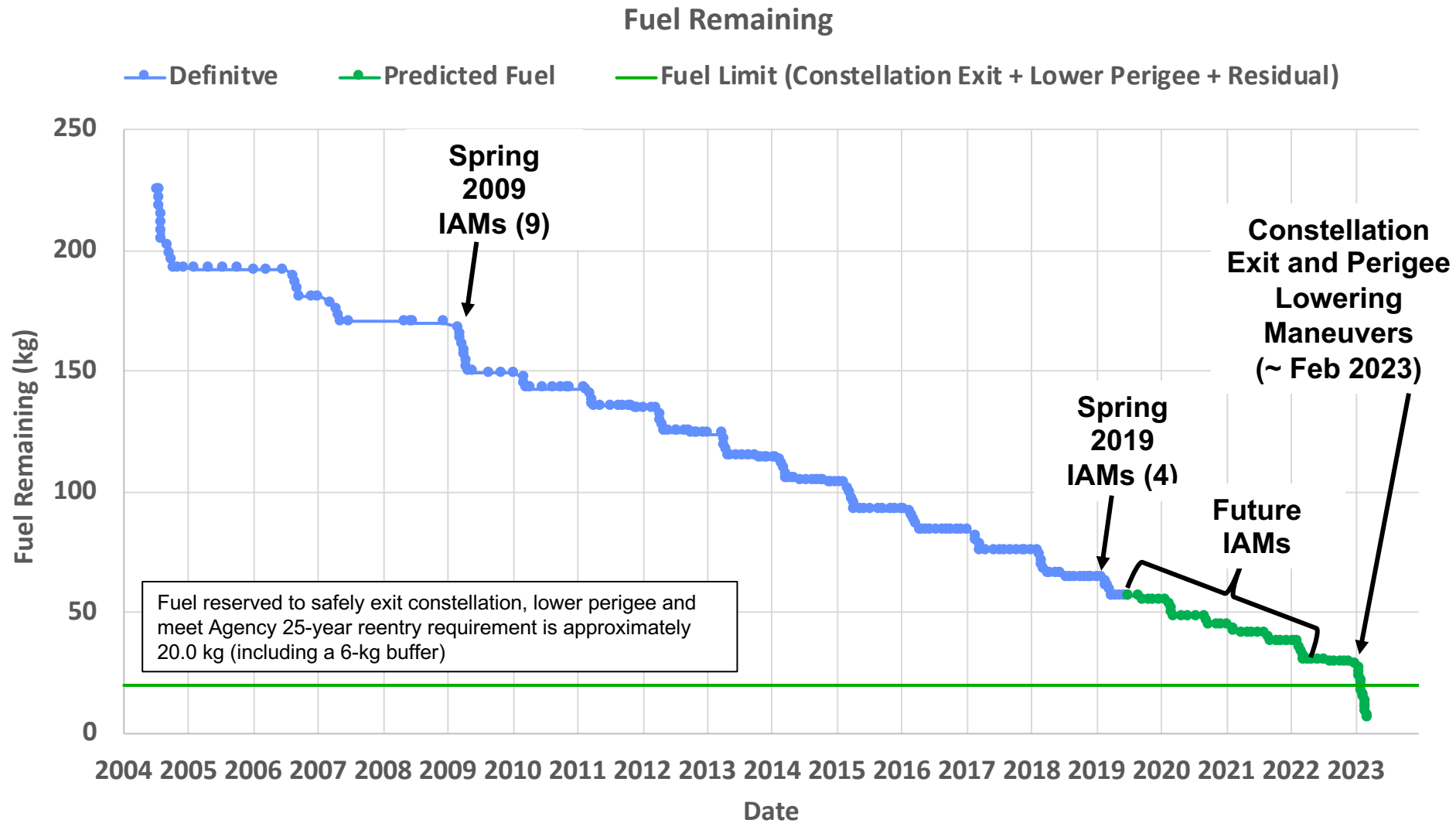
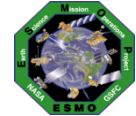
Timeline

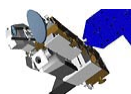


- **January 2018 – Senior Review (2017) Guidance Letter Response** included plans to assess implications of two potential measures to save fuel:
 - Discontinue Inclination Adjust Maneuvers (IAMs) and exit the A-train early
 - Utilize the Reaction Wheel Assemblies (RWAs) to supplement thrusters during maneuvers → successfully executed in Spring 2019
- **09/11/2018 (De Bilt, Netherlands) – OMI Science Team Meeting**
 - Operations and science teams held splinter discussion about the implications of changing Aura's orbit (added to MOWG agenda)
- **11/08/2018 (@GSFC) – Aura Mission Ops & Science Team Quarterly**
 - Updated overall Aura Mission Status and Early A-Train Exit planning
- **12/06/2018 (@GSFC) – Earth Science Constellation (ESC) MOWG**
 - Presented Aura exit cases for comments by the A-Train member missions
- **06/03/2018 (@CNES) – Earth Science Constellation (ESC) MOWG**
 - Presented Aura exit cases and updated analysis for comments by the A-Train member missions
- **May/June 2019 – Updated Future Power Generation Analysis**
 - Concerns with power generation capability arise as the beta angle drifts after constellation exit

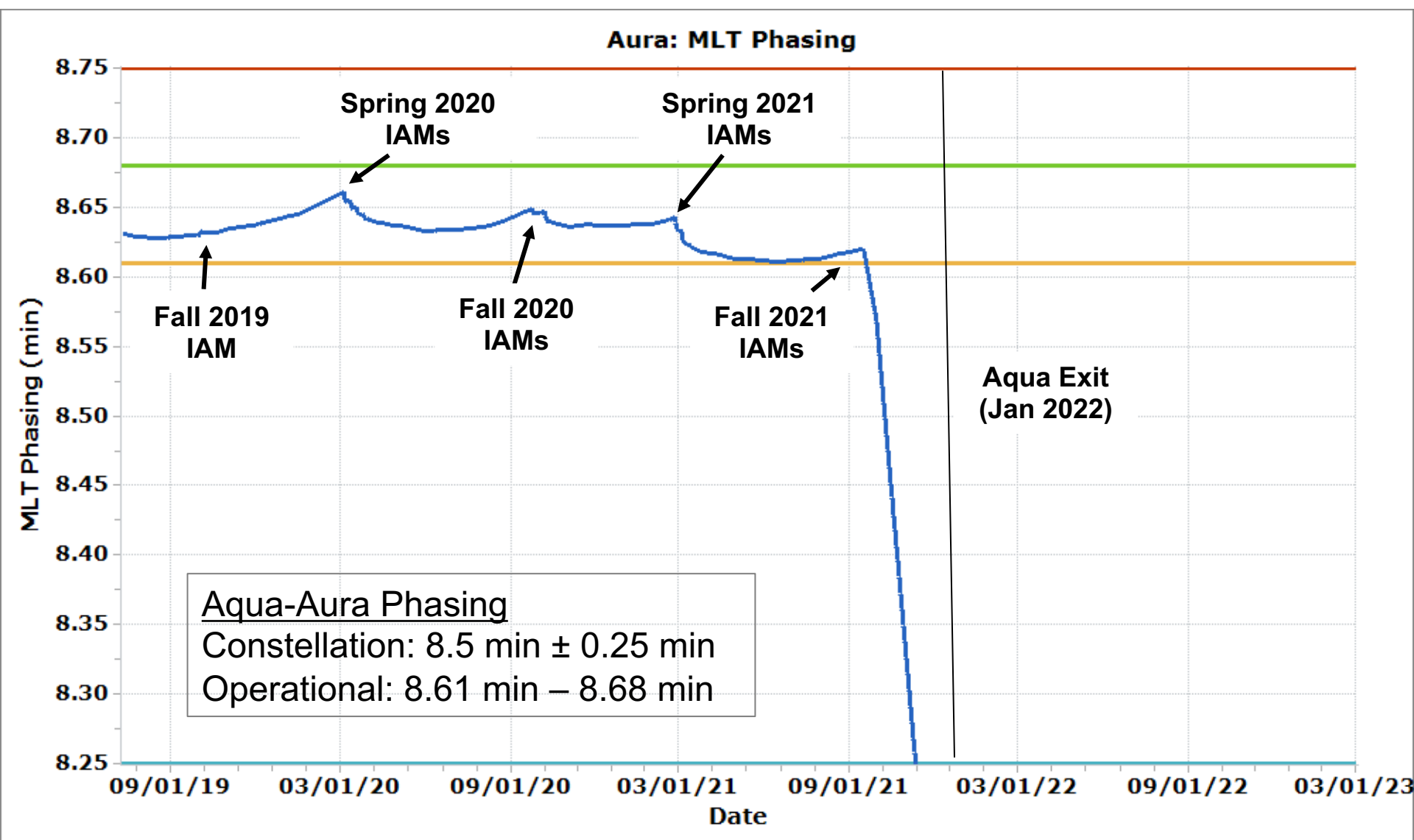
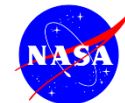
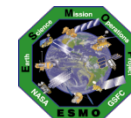


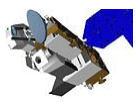
Fuel Remaining



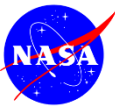
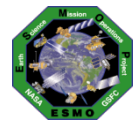


Aqua / Aura Phasing

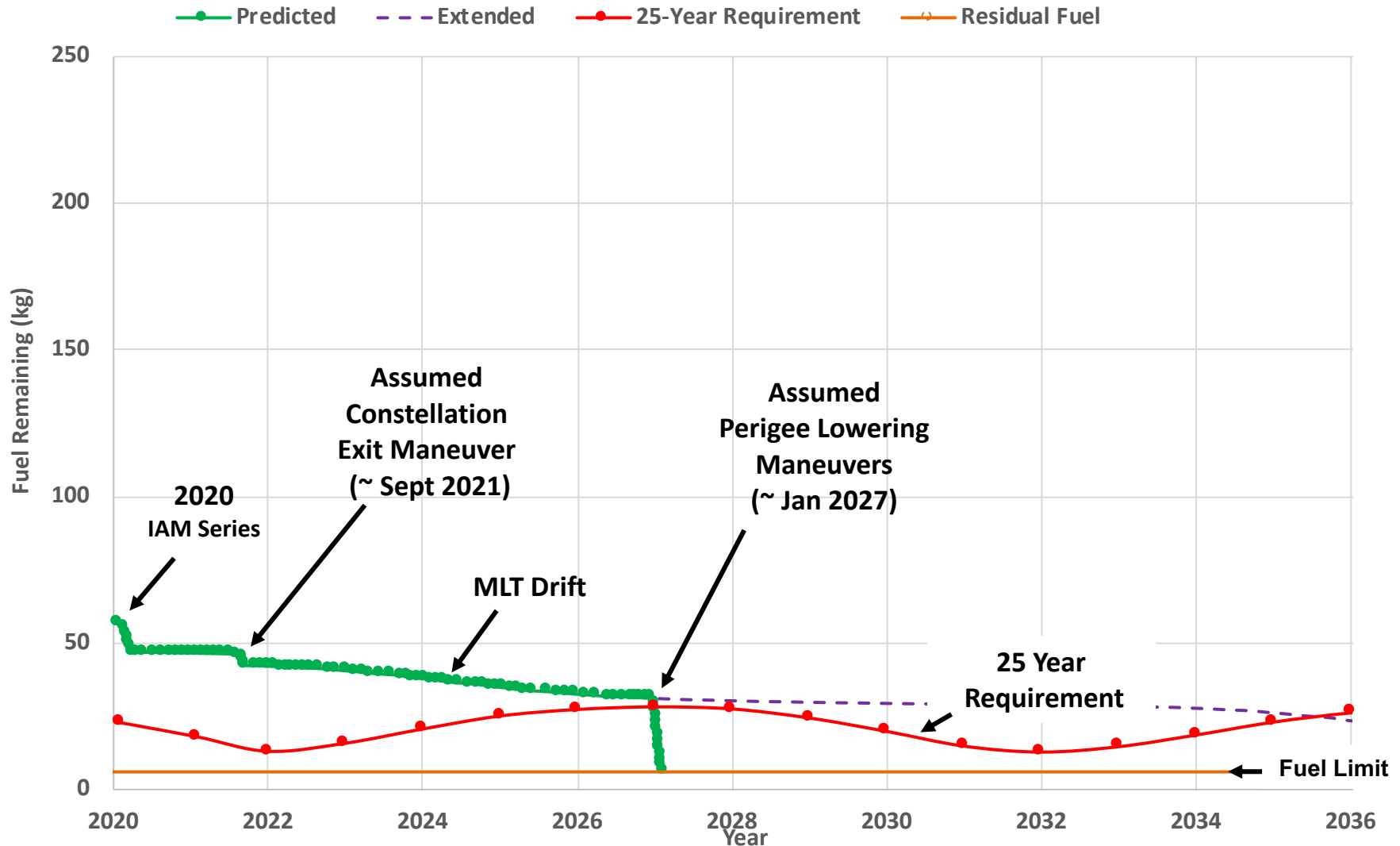


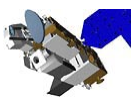


Alternate Fuel Usage Case

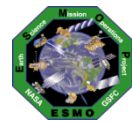


Aura DAS End of Life Predictions (Analysis Updated May 2019)



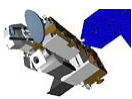


Aura Future Power Generation

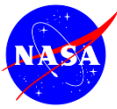
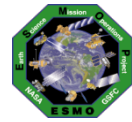


Aura Future Power Generation Analysis:

- Working as part of the Electrical Power Subsystem (EPS) Power Working Group (PWG) with the Flight Ops Team (FOT), Northrop Grumman (NG), and Engineering & Technology Directorate (GSFC ETD)
- Determine how the Angle of Incidence (AOI) between the sun and the solar array affects the power that can be generated at given conditions
- Specifically, determine at what Angle of Incidence (AOI) the satellite is no longer able to generate enough power to sustain loads and charge batteries
- Analysis explores the two cases for the future orbit given the baseline or alternate fuel usage cases:
 - Obtained Beta Angle predictions from Flight Dynamics System (FDS)
 - Obtained Earth-Sun Distance predictions from JPL's HORIZONS
 - Used Weibull Analysis to predict number of remaining solar strings
 - Used Previous Spring and Fall State-of-Health (SOH) Test data to predict how the Power-per-String (PPS) will degrade
- **Analysis updated in June 2019**

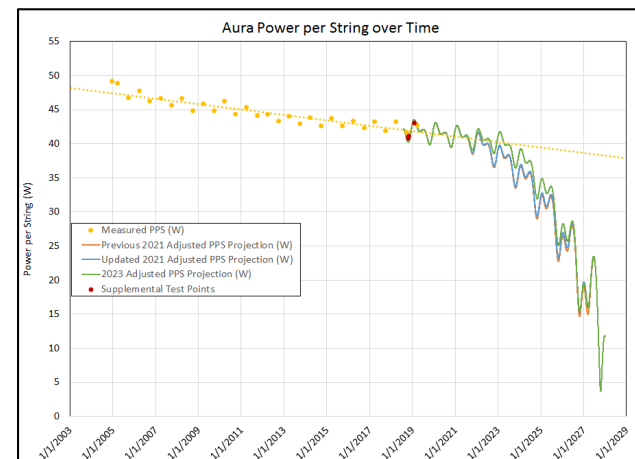
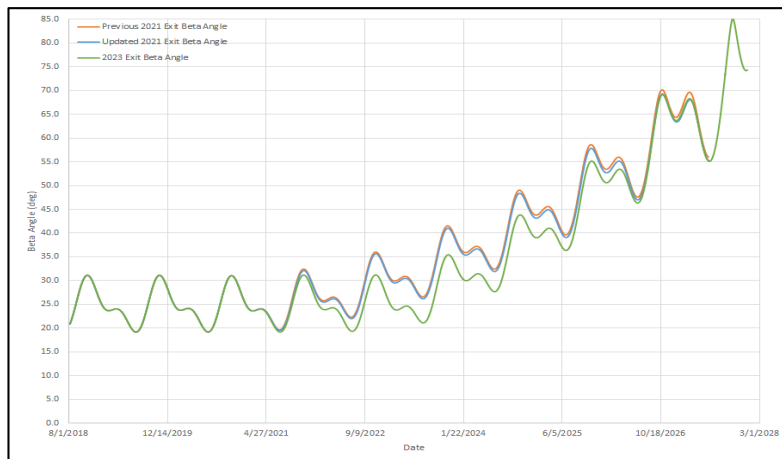


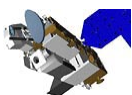
Aura Future Power Generation



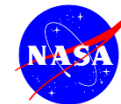
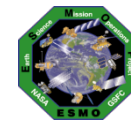
Method:

- Determine the Incident Sunlight Intensity Factor (ISIF) for each day given the Beta Angle and Earth-Sun Distance
 - $$ISIF = \cos(Beta\ Angle) \cdot \frac{1}{(Earth-Sun\ Distance)^2}$$
- Adjust the Power per String (PPS) Projection to account for different ISIFs
- Determine Minimum Strings Required Projection based on the Adjusted PPS projection
- Determine when the Strings Remaining Projection drops below the Minimum Strings Required Projection





Aura Future Power Generation Analysis



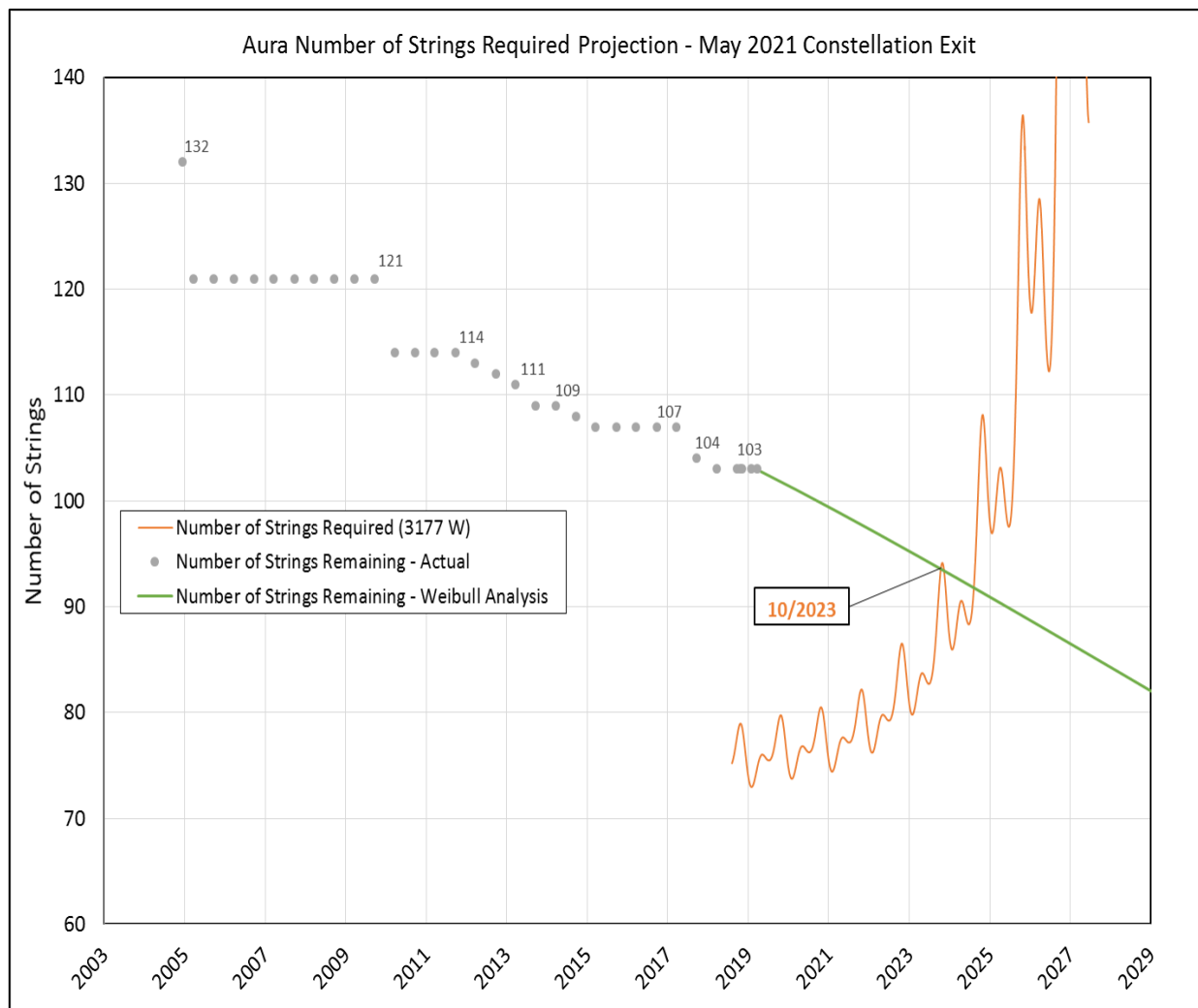
2021 Constellation Exit – Power Margin

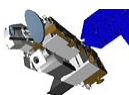
Current power margin analysis estimates the **Minimum Required Power for Loads and Battery Charging = 3177 W**

Current best estimates for the 2021 exit case predict the power margin threshold would be violated in approximately **October 2023**

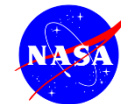
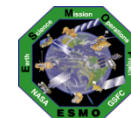
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The solar array strings remaining projection comes from the Code 371 Weibull Analysis (updated 3/15/2019)

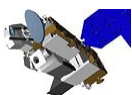




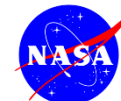
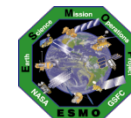
Case Comparison



Alternate Fuel Usage Case (2021 Constellation Exit)	Baseline Fuel Usage Case (2023 Constellation Exit)
<ul style="list-style-type: none">- Science record at the 705 km A-Train orbit (17 years [2004-2021])	<ul style="list-style-type: none">- Science record at the 705 km A-Train orbit (19 years [2004-2023])
<ul style="list-style-type: none">- New science record to begin in 2021 after constellation exit (4.4 km lower)	<ul style="list-style-type: none">- New science record to begin in 2023 after constellation exit and perigee lowering (new orbit 650 – 695 km)
<ul style="list-style-type: none">- Conserve fuel by eliminating IAMs which allows for more fuel in reserve to re-enter <25 years	<ul style="list-style-type: none">- Reach fuel limit in 2023 which drives need for constellation exit and perigee lower maneuvers to meet 25-year re-entry
<ul style="list-style-type: none">- Power generation concerns begin around late-2023	<ul style="list-style-type: none">- Power generation concerns begin around late-2024
<ul style="list-style-type: none">- As the beta-angle and MLT drift, new instrument products and calibrations will be necessary (starting in 2021)	<ul style="list-style-type: none">- As the beta-angle and MLT drift, new instrument products and calibrations will be necessary (starting in 2023)



Abbreviations / Acronyms List



AOI –	Angle of Incidence	IAM –	Inclination Adjustment	SR –	Senior Review
CEM –	Constellation Exit Maneuver		Maneuver	SRP –	Senior Review Proposal
CNES –	Centre National d’Etudes Spatiales	ISIF –	Incident Sunlight Intensity Factor	STM –	Science Team Meeting
DAS –	Debris Assessment Software	JPL –	Jet Propulsion Lab	TROPOMI –	Troposphere Measuring Instrument
deg –	degrees	KDP-F –	Key Decision Point for Phase F	W –	watts
DMU –	Drag Make-up Maneuver	kg –	kilogram	WRS –	World Reference System
DR –	Decommissioning Review	km –	kilometer		
DRR –	Disposal Readiness Review	min –	minutes		
EPS –	Electrical Power System	MLS –	Microwave Limb Sounder		
ESC –	Earth Science Constellation	MLT –	Mean Local Time		
ESMO –	Earth Science Mission Operations	MOWG –	Mission Operations Working Group		
ETD –	Engineering & Technology Directorate	NASA –	National Aeronautics & Space Administration		
FDS –	Flight Dynamics System	OMI –	Ozone Monitoring Instrument		
FY –	Fiscal Year	PLM –	Perigee Lowering Maneuver		
GSFC –	Goddard Space Flight Center	PPS –	Power Per String		
GTE –	Ground Track Error	PSO –	Project Science Office		
HQ –	Headquarters	PWG –	Power Working Group		
INST –	Instruments	RWA –	Reaction Wheel Assembly		
		SMA –	Semi-Major Axis		
		SOH –	State of Health		